down again as the last strongholds of the old technology are penetrated until the old technology is totally replaced.

Through experience, my colleagues and I have found a particular set of models—namely, the Fisher-Pry model and its extensions—to provide the most accurate description of this process, and accordingly, to generally be the most useful for forecasting technological substitutions. This finding applies to both telecommunications and other industries. In fact, more than 200 substitutions, in industries ranging from chemicals to aviation, have been identified which fit the Fisher-Pry pattern.

Since the pattern of how a new technology replaces an old technology is consistent, the forecaster can apply the pattern to a technology substitution in progress to forecast the remainder of the substitution and to estimate the end date for the old technology. Substitution patterns can also be used to estimate the survivor curve, from which the Average Remaining Life (ARL) can be calculated. More information on substitution analysis, the Fisher-Pry model, and its relationship to depreciation is given in Exhibit 3.

Although no forecasting method is perfect, our experience with the model indicates that it provides very accurate forecasts of equipment lives. I periodically review actual data and compare it with prior Fisher-Pry forecasts, and generally find the forecasts to have accurately predicted subsequent data, especially when compared with other explicit and implicit forecasts that were made at the same time.

An example is a forecast that TFI prepared in 1986 for the substitution of stored program control (SPC) switching for electromechanical switching by major local exchange carriers. Exhibit 4 shows the 1986 forecast. The hollow boxes show the data that was available for the forecast. The forecast was presented as a range within which the substitution pattern would likely fall, as shown by the shaded area. In 1986, TFI predicted that there would be virtually no access lines served by electromechanical equipment sometime between 1993 to 1995. The actual data for subsequent years, shown by the solid boxes, traces the "early" forecast almost exactly.

Substitution analysis provides better indicators of lives than mortality-based methods because substitution analysis recognizes that technological obsolescence is the major driver for retirements. As I discussed earlier, analysis of recent retirement and investment data could not have predicted the rapid retirements of electromechanical switches between 1975 and 1980 (the "avalanche" shown in Exhibit 2). Using historical data, a substitution analysis performed as early as 1970 would have predicted the avalanche. History is repeating itself now. Substitution analyses done in the mid- to late-1980s predicted the avalanche that is burying the analog ESS accounts of the major LECs today.

Another important point is that substitution analysis measures technology in terms of physical units in use. For example, we forecast access lines in service or equivalent circuits in service. Beside measuring in physical units rather than dollars, substitution analysis reflects whether a unit of investment is useful as opposed to whether it is retired. On fundamental principals, usefulness is the better depreciation measure because it reflects the productive value of an asset. Also, because of the potential lag between the end of an asset's useful life and its retirement, retirements are typically a late indicator of major changes in an account. Following the avalanche curves, obsolesence-based retirements show up only after the story is almost over. Measuring units in use, on the other hand, provides a leading indicator. The only good reason to base depreciation lives on retirements was that accounting data is kept on that basis. However, now that ARMIS data is reported regularly to the FCC, the information to measure productive lives is readily available.

In general, we have applied substitution analysis to industry trends to obtain industry forecasts. However, individual companies have successfully prepared forecasts on a company level. Also, prior studies have shown that industry trends are a reliable guide for an individual company's projections, although some variation can be expected. This makes sense in an industry as interconnected as the telephone industry and where most companies use the same suppliers. (With only several key suppliers, the same technology is made available to all local exchange carriers, at similar prices, even though they are geographically dispersed.) In addition, with the increasing competition I described, it will be imperative for individual companies to at least keep up with the industry.

Lives for Metallic Cable

The outside plant is traditionally split into underground, buried, and aerial accounts. From the viewpoint of cable wearing-out or breaking, this is a logical categorization; but when technological obsolescence is the driver for change, the categorization is less useful. In applying technology forecasting, we have, instead, distinguished between interoffice, feeder, and distribution plant, which are spread among the three traditional accounts.[2] We chose this approach because technology is being adopted differently and at different times in the interoffice, feeder, and distribution parts of the exchange network.[3] Also, some of the driving forces of change are different.

Interoffice Cable

The interoffice plant is now 95% digital and over 67% fiber, as measured by equivalent circuits in use.[4] Thus, there is relatively little metallic investment still being used in the interoffice environment. Almost all new investment is fiber and the metallic carrier share has declined steadily. By the year 2000, essentially all interoffice circuits will be on fiber.

Our forecast for the adoption of fiber, and the displacement of non-fiber facilities, is based on a multiple substitution analysis of historical data through year-end 1992 and planning data through year-end 1995.[5]

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[2] *Interoffice* facilities connect telephone company central offices (where the switches are located) with each other. *Feeder* facilities are cables that extend from a central office toward the neighborhoods and business areas served by the central office. A typical feeder cable usually serves a large number of customers. The *distribution* network extends from the termination of the feeder facilities to residences and businesses.

[3] For example, most interoffice facilities today are fiber optic systems, while most feeder facilities are provided on copper cables. However, the use of fiber optics in the feeder network is growing rapidly. In the distribution network, copper cable is by far the most common technology, although fiber optic systems are beginning to be adopted.

[4] *Source*: Year-end 1992 ARMIS data reported to the FCC.

[5] The historical data for 1980-1989 is from TFI files, the historical data for 1990-1992 is from ARMIS reports filed with the FCC, and the planning data for 1993-1995 is the weighted average from the seven local exchanges carriers (representing over 90 million working access lines in 1993) that provided us planning data. (We used the planning data in our forecast because we have generally found that the first several years of planning data is reliable and improves mid- to long-range forecasts.)

Exhibit 5 shows the percentage of circuits served by each of the major technology types. The historical and planning data is shown by the hollow circles or squares. For interoffice copper, the analysis indicates an average remaining life (ARL) of 2.8 years.[6]

Feeder Cable

In the feeder plant, Digital Loop Carrier (DLC) facilities have been displacing (or stranding) copper pairs for many years. Both metallic-based and fiber-based DLC systems are being adopted, although fiber DLC systems are beginning to dominate. (Even metallic-based systems strand tremendous amounts of copper investment because they carry many subscriber lines on only a few copper conductors.)

Our forecast for the adoption of DLC systems, and the displacement of analog copper facilities, is based on a multiple substitution analysis of historical data through year-end 1992 and planning data through year-end 1995.[7] Exhibit 6 shows our forecasts for the percentage of access lines served by each of the major technology types. The historical and planning data is shown by the hollow circles or squares. For copper feeder, the analysis indicates an ARL of 8.0 years.[8]

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[6] This was calculated by estimating a survivor curve for the non-fiber interoffice facilities from Exhibit 5.

[7] The historical data for 1980-1989 is from TFI files, the historical data for 1990-1992 is from ARMIS reports filed with the FCC, and the planning data for 1993-1995 is the weighted average from the eight local exchanges carriers (representing over 100 million working access lines in 1993) that provided us planning data. While DLC will continue to substitute for feeder copper, FITL systems will also impact feeder copper facilities in the same manner it will distribution facilities. With very few exceptions, FITL will require fiber feeder. Thus, we incorporated the FITL adoption into the feeder multiple substitution analysis.

Distribution Cable

The principal impact on metallic distribution facilities is the deployment of Fiber in the Loop (FITL) in order to meet the emerging demand for new wideband (1.5 Mb/s) and broadband services (45 Mb/s and above). By FITL we mean any architecture that extends fiber to an area of no more than several hundred customers; the last link to the customer may be on copper pairs, coaxial cable, or fiber. Wideband and broadband data rates are needed for most of the emerging telecommunications applications we mentioned. Our analysis also shows that wideband will play a dominant role from the late 1990s through 2010 for most two-way, end-to-end digital services. However, television services with picture quality comparable to existing cable service will require broadband access from the beginning.

Our analysis of distribution facilities is based on the average of two industry scenarios for the adoption of FITL. Each of these scenarios is based on composite forecasts of the demand for wideband and broadband services. The first scenario assumes that fiber is deployed rapidly to meet the emerging demand for new wideband services at 1.5 Mb/s or similar data rates. The second scenario assumes that wideband services are deployed on copper pairs using improved T1 technologies and that fiber is not rapidly adopted until the demand for broadband services (45 Mb/s and above) emerges.

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[8] This was calculated by estimating the survivor curve for analog feeder investment. The survivor curve was estimated from the analog forecast shown in Exhibit 6, after adjusting for the percentage of access lines that do not represent any feeder investment.

Exhibit 7 shows the forecasts for the demand for wideband and broadband services, along with the fiber deployment needed under each scenario. These services and their impacts were the subject of TFI's *New Services Study* completed in 1993.[9] We analyzed the benefits, drivers, and constraints for applications such as advanced fax, computer-based imaging, interactive multimedia, LAN interconnection, video communications, and interactive television. We then prepared forecasts for the adoption of each and combined them into an overall forecast for digital services. The study also examined the bandwidth requirements of each application, which led to separate forecasts for narrowband, wideband, and broadband services.

For the industry, we took the average of the two scenarios because the choice between fiber and copper for wideband services will be a balancing act for LECs. If they over-invest in the copper strategy, they risk entering the next century with an obsolete network, after having sunk large amounts of money into equipment to enhance the copper technology. On the other hand, they cannot get fiber to everyone simultaneously, and even if they could, it might not be the best plan financially. The averaging approach avoids the two extremes, with wideband services being provided on copper in the early years, then migrating to fiber as demand increases and costs fall. However, many companies will adopt fiber strategies that will be much closer to the early adoption scenario because, given the increasingly competitive nature of the industry, this is a less risky strategy. For companies that want to realistically compete in the provision of standard cable television services, as opposed to what has been called VCR-quality interactive services, the early adoption scenario is a necessity. For these reasons, we believe that the

[9] These are listed among the references in Exhibit 1.

averaging process we used may actually underestimate the adoption of FITL for most companies.

The data for the two original scenarios and the average scenario is shown in Exhibit 8. The result is a likely industry ARL of 12.1 years for copper distribution facilities. Companies that aggressively adopt fiber optics will experience average remaining lives of as low as 9.4 years. These estimates do not take into account the impact of competition. TFI's 1993 personal communications study showed that competition from wireless technologies alone could reduce remaining economic lives for copper cable to as low as 7.3 years, even under the average fiber adoption scenario.[10]

Metallic Cable, Composite Lives

Ignoring competition, we recommend average remaining lives of 2.8 years for interoffice copper, 8.0 years for copper feeder, and 9.4 to 12.1 years for distribution. About 5% of current metallic outside plant investment is in interofffice facilities, with the remainder divided equally between feeder and distribution. Thus, a composite ARL for copper outside plant should be between 8.4 and 9.6 years.[11]

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[10] Ralph C. Lenz and Lawrence K. Vanston, ***Personal Communications:*** ***Perspectives, Forecasts, and Impacts*** (Austin, TX: Technology Futures, Inc., 1993).

[11] This is a weighted average. For the lower value: 5% × 2.8 years+47.5% × 8 years +47.5% × 9.4 years = 8.4 years. For the higher value: 5% × 2.8 years + 47.5% × 8 years + 47.5% × 12.1 years = 9.6 years.

Since underground cable is mostly interoffice and feeder, an ARL of 7.5 years is recommended for that account.[12] For a typical company, this ARL corresponds to a projection life of about 15 years for the installed base of equipment.

Lives for Analog Circuit Equipment

The analog circuit account includes analog carrier equipment and various other equipment for use in an analog environment, notably Metallic Facility Termination (MFT) equipment used for line treatment and conditioning on subscriber private-line loops and Switched Maintenance Access System (SMAS) test equipment used to test individual analog circuits.

Analog carrier equipment has no economic value, but, in a few places, has yet to be officially retired. It simply has no place in a digital network. The appropriate remaining lives of this equipment should be zero or at least very, very low.

The other analog circuit categories are also basically obsolete. Conditioned lines are usually used for private lines that carry data traffic via modems, at faster data rates than can be handled on standard lines. In many cases, digital private lines are replacing conditioned analog lines for these applications; in others, improved modems allow the same data rates over unconditioned lines. SMAS test capability is being replaced by digital circuit equipment such as Digital Access and Crossconnect Systems (DACS).

[12] This is a weighted average computed from the relative investments in feeder and interoffice facilities: 10% × 2.8 years + 90% × 8years=7.5 years.

To keep things simple, we estimate the life of the entire analog circuit account by tying it to the demise of the analog central office environment, in particular the demise of analog switching. This is conservative since much of the account, especially analog carrier, will be gone before analog switching. Our forecast for analog switching, shown in Exhibit 9, yields an ARL of 2.2 years. Thus, we recommend this as the maximum reasonable life for analog circuit equipment. For a typical company, this ARL corresponds to a projection life of about 6 years.

Lives for Fiber Cable

Presently, there is not a clear technology replacement for fiber optic cable. To date, improvements in fiber systems have concentrated on the associated electronics. For this reason, we did not apply the same type of substitution analysis that we have for the other accounts This is not to say that fiber investment will have especially long lives.

As identified by GTE Labs and Bellcore, there are four major factors impacting fiber lives: technological obsolescence, topological obsolescence, mechanical degradation, and optical degradation. Technological obsolescence is to be expected even if the successor technology is not obvious today. We have already seen one generation of fiber optics be replaced, as multi-mode fiber made way for single-mode fiber. Also, manufacturers continue to improve the basic properties of fiber such as in flexibility, strength, clarity, transmission quality, reflectivity, refractivity, and durability. Topological obsolescence is where the location, routing, sizing, or architecture of a fiber installation later proves wrong. Finally, fibers eventually will "go dark" with age or crack, causing degradation in transmission capability. Although more careful fiber specification and installation has improved fiber lives, eventual wear-out is still a factor.[13] Putting these factors together, the best available technical judgement indicates the projection life of fiber should be 20 years and that anything more puts the recovery of capital in jeopardy.[14]

Because of competition, any investment in the local exchange network now has an element of risk. The investment and accounting communities must reflect this risk in evaluating assets.[15] Although, from a technological viewpoint, a projection life of 20 years is appropriate, I believe there should be a downward adjustment for the risk factor. Obviously, the appropriate amount involves some judgment that strays from the realm of both mortality analysis and technology forecasting. That said, my judgment calls for a projection life of between 10 and 15 years for most businesses. Given that LECs are generally well-managed and financially healthy, I believe that 15 years would be an appropriate projection life for fiber cable. Thus, I recommend a life of 15 to 20 years, depending on whether the risk factor is considered.

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13 The physical properties of fiber are very different from those of copper, and their physical lives are affected by different factors. Thus, historical copper lives provide no guidance in estimating fiber lives.

14 Craig M. Lemrow, Corning Glass Works, "How much stress can fiber take?" *Telephony* (May 23, 1988):82. Also, *Generic Requirements for Optical Fiber and Optical Fiber Cable*, Bellcore Technical Advisory, Issue 8 (TA-NWT-000020, December 1991), p. 2.

15 Competitive risk was addressed by Moody's Investors Service (see *Telecommunications Reports* [December 6, 1993]:5) with its recent warning: "In addition, it says the trend toward telephone companies entering each other's local exchange markets through alliances with cable TV operators and the prospect of new wireless services have increased the

Lives for Digital Circuit Equipment

Digital circuit equipment is not included among the initial accounts for simplification, but technology forecasting also applies to this account.

The digital circuit equipment account includes a variety of different equipment types, some very modern and some quite old and nearing obsolescence. However, virtually *all* circuit equipment will be impacted by SONET technology. Thus, forecasting the adoption of SONET allows us to calculate an upper bound on the productive life of any type of circuit equipment.

SONET is a format for organizing information on a fiber optics channel that recognizes the need for integrating different types of traffic on the same pair of fibers. Among its many advantages is standardized optical and electrical interfaces that all suppliers will adhere to. Another is that an individual information stream on a fiber channel can be efficiently separated from the rest of the information on the channel. These features are essential to efficient and economical digital information highways.

Exhibit 10 shows our forecasts of the percentage of capacity on SONET for the interoffice and loop environments, respectively. These forecasts are based on the Fisher-Pry model applied to planning data from nine LECs. By 2005, essentially all currently-deployed digital circuit equipment will have been replaced by SONET equipment. Combining the interoffice and loop forecasts implies a weighted ARL for digital circuit equipment of 4.6

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competitive risk at the local loop level 'significantly.' Telco's debt ratings 'are likely to be downgraded as a result.' " The same risk to the telco's debt is faced by the telco's assets.

years.[16] For existing digital circuit equipment, this ARL implies a projection life of about nine years for a typical company.

Lives for Digital Switching Equipment

As with digital circuit equipment, digital switching is not included among the initial accounts for simplification, but, again, technology forecasting is applicable.

There are two factors to consider in computing digital switching lives. First, digital switches use a modular architecture that allows individual components of the switch to be upgraded independently. This creates interim retirements of the components that are upgraded. At the end of the life of a switch entity, most of its components will likely have been replaced at least once. Second, today's switch architectures, flexible as they are, will ultimately be replaced by a new switching architecture based on ATM.

Our approach to estimating digital switching lives is to divide the switch into its major components and to estimate the life for each component using technology forecasting. Then, a composite life is estimated by weighting the component lives by their percentage of switch investment. This analysis yields a composite ARL of 7.6 years. The table below illustrates the process:

[16] This is a conservative estimate because, in addition to SONET, there are other drivers that will cause particular types of digital circuit equipment to be retired before the year 2000. First, D-channel banks have been and will continue to be replaced by Digital Crossconnect Systems, as well as by direct interfaces to digital switches. Second, T-1 terminal equipment and repeaters are retired when fiber optics systems are deployed. Third, Central Office Digital Loop Carrier (DLC) terminals are being replaced by direct DLC interfaces into switches, which also eliminates the need for line cards on the switch.

Digital Switching—Modular Retirement Analysis

Component	Pct of Investment	Average Remaining Life (years)	Contribution (years)
Processor/Memory	14%	5.1	0.71
Switching Fabric	5%	7.3	0.37
Trunk Interface	13%	5.5	0.72
Line Interface-Analog	50%	8.0	4.00
Line Interface-Digital	11%	7.3	0.80
Shell	7%	13.8	0.97
Composite	100%	Composite ARL =	7.56

The component lives were estimated by a combination of forecasting methods.[17] The shell is the part that is not modular and will last the life of the switch entity. It has the longest life, but because its percentage of the switch investment is so small, it has scant influence on the composite life of the switch.

The composite ARL of 7.6 years also serves as a reasonable estimate of the projection life for digital switching equipment installed today. This is a reflection of the point I made earlier with regard to avalanche curves: When technology obsolescence is the driver for change, the projection life for new equipment is roughly the same as the ARL for existing equipment. The observation applies here because the current ARL is heavily influenced by the upcoming obsolescence of line and trunk interface equipment caused by SONET, digital loop carrier, fiber in the loop, and new digital services,

[17] For example, the trunk interface and digital line card lives are based on SONET adoption forecasts presented above, with a two-year lag added to account for the delayed impact on switching. The life for the largest component, analog line interfaces, was based on the forecasts of the adoption of digital loop carrier and FITL, presented above, as well as the impact of new digital services such as narrowband ISDN on non-DLC access lines.

including narrowband ISDN. For *existing* equipment, the corresponding projection life depends on the company. For a company that invested in digital switching early, the ARL of 7.6 years may correspond to a projection life of 13 years, while for another company with newer equipment the same ARL may correspond to a projection life of 10 years. This reflects another of the points regarding avalanche curves: When technology obsolescence is the driver for change, equipment purchased later in a technology generation will have a much shorter life than equipment purchased earlier.

Summary

We have forecast the adoption of new technology in the telephone network and developed average remaining lives for several major categories of network equipment. The recommended lives on the table (next page) are industry averages, although they should generally apply to individual companies with modest variation.

These lives are significantly shorter than those used in regulatory accounting. They reflect the realities of technological change and the need to provide advanced communications services. They do not, however, fully reflect the impact of competition on the economic life of equipment and, therefore, may be too long. As competition continues to dominate the local exchange network, the adoption of realistic equipment lives will become critical to the survival of local carriers. This not only requires depreciation simplification, but also a realistic methodology and correspondingly realistic lives.

Technology	Recommended Industry Average Remaining Life (Years)	Corresponding Projection Life (Years)[a]
Outside Plant		
Interoffice Cable, Metallic	2.8	
Feeder Cable, Metallic	8.0	
Distribution Cable, Metallic	9.4-12.1[b]	
Metallic Cable, Averaged	8.4-9.6[b]	
Underground Cable, Metallic	7.5	15
Cable, Non-Metallic, All Types	-	15-20[c]
Circuit Equipment		
Analog	2.2	6
Digital	4.6	9
Switching Equipment		
Analog	2.2	-
Digital	7.6	10-13[d]

[a] The ranges specified by the FCC should include these projection lives (or range of lives). These are industry averages; some companies may have lower or higher projection lives. Note: The projection life is for the installed base, not newly-installed equipment, and depends on the particular distribution of plant a company has.

[b] Ignoring competition for voice access services.

[c] The 15-year projection life reflects risk due to competition.

[d] This is a reasonable range of projection lives that correspond to the recommended industry ARL of 7.6 years. Companies with a shorter ARL may have a projection life of less than 10 years.

Exhibit 1

Telecommunications Technology Forecasting Group
Publication List

Comparisons of Technology Substitutions in Telecommunications and Other Industries, Ralph C. Lenz and Lawrence K. Vanston (1986).

The Effects of Various Levels of Aggregation in Technology Substitutions, Ralph C. Lenz and Lawrence K. Vanston (1987).

Technological Substitution in Transmission Facilities for Local Telecommunications, Lawrence K. Vanston and Ralph C. Lenz (1988).

Technological Substitution in Switching Equipment for Local Telecommunications, Lawrence K. Vanston and Ralph C. Lenz (1989).

Technological Substitution in Circuit Equipment for Local Telecommunications, Lawrence K. Vanston (1989).

Future Technology in the Local Telecommunications Network, An Expert Opinion Survey, Lawrence K. Vanston and William J. Kennedy (1989).

A Facsimile of the Future: Forecasts of Markets and Technologies, Lawrence K. Vanston, William J. Kennedy, and Samia El-Badry-Nance (1991).

Computer-Based Imaging and Telecommunications: Forecasts of Markets and Technologies, Lawrence K. Vanston, Samia El-Badry-Nance, William J. Kennedy, and Nancy E. Lux (1992).

Interactive Multimedia and Telecommunications: Forecasts of Markets and Technologies, Julia A. Marsh and Lawrence K. Vanston (1992).

Local Area Network Interconnection and Telecommunications, Bruce R. Kravitz and Lawrence K. Vanston (1992).

Video Communications, Lawrence K. Vanston, Julia A. Marsh, and Susan M. Hinton (1992).

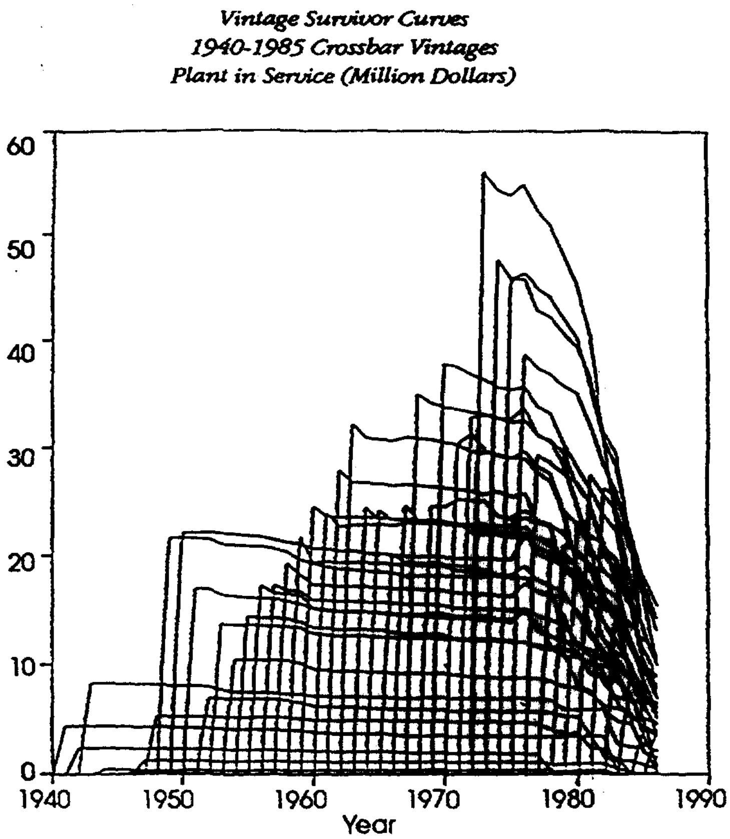
Telecommunications for Television/Advanced Television, Lawrence K. Vanston, Julia A. Marsh, and Susan.M. Hinton (1992).

New Telecommunications Services and the Public Telephone Network, Lawrence K. Vanston (1993).

Personal Communications: Perspectives, Forecasts, and Impacts, Ralph C. Lenz and Lawrence K. Vanston (1993).

Exhibit 2

Vintage Survivor Curves for Crossbar Switching—Illustration of Avalanche Effect



Source: Bellcore

Substitution Analysis and the Fisher-Pry Model

Lawrence K. Vanston

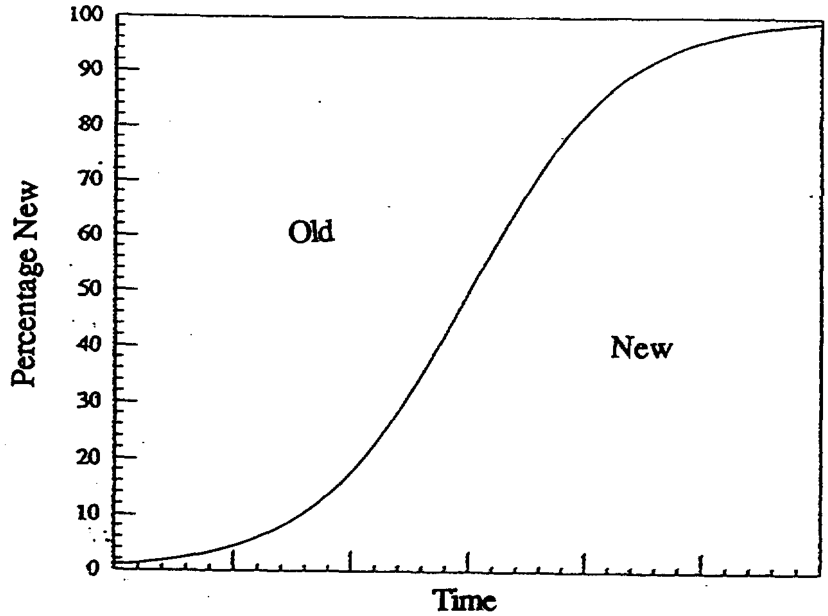
Technology Futures, Inc.

Substitution analysis examines patterns of technology substitution—a pattern which is remarkably consistent from one substitution to another. The adoption of a new technology starts slowly. As the new technology improves, it becomes generally recognized as superior. The old technology, because of inherent limitations, experiences falling market share.

If the percentage of the total market captured by a new technology is plotted over time, an S-shaped curve results. Experience shows that a particular set of models, namely, the Fisher-Pry model and its extensions, are most useful for forecasting. The model was first described by Fisher and Pry in 1971.[1] It has been shown to be appropriate for substitutions in both telecommunications and other industries. More than 200 substitutions, in industries ranging from chemicals to aviation, have been identified that fit the Fisher-Pry pattern.[2] The S-shaped curve defined by the Fisher-Pry model is shown in Figure 1.

[1] J. C. Fisher and R. H. Pry, "A Simple Substitution Model of Technological Change," *Technological Forecasting and Social Change* 3 (1971), pp. 75-88.
[2] R. C. Lenz and L. K. Vanston, *Comparisons of Technology Substitutions in Telecommunications and Other Industries* (Austin, TX: Technology Futures, Inc., 1986).

Figure 1
The Fisher-Pry Model



Mathematically, the model can be written:

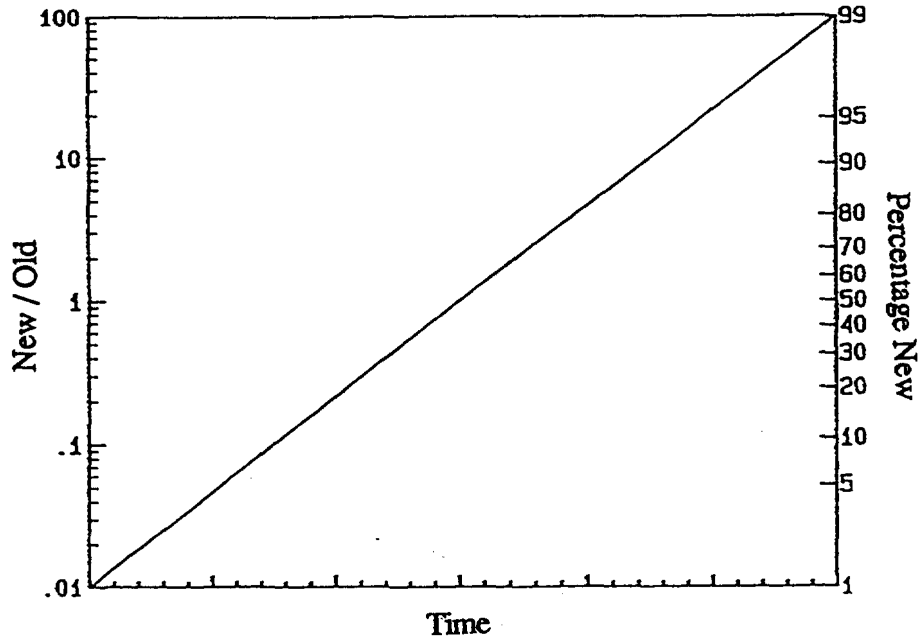
$$y(t) = 1 / (1 + e^{-b(t-a)})$$

where **y(t)** is the fraction of the new technology at time **t**. The parameter **a** is the time the new technology reaches 50% of the total universe of the old and new technology. The parameter **b** measures how fast the substitution proceeds. Another commonly-used measure for the rate of substitution is the Fisher-Pry annual substitution rate, defined as $\mathbf{r = (e^{b}-1) * 100\%}$.

The shape of the curve is remarkably constant from substitution to substitution. However, the time period over which the substitution takes place varies greatly from one to another. In electronics, complete substitution may occur in less than 10 years, while complete substitution may take over 20 years for some telecommunications substitutions. This time period is related to the substitution rate for a particular substitution.

The ratio of the new technology to the old technology is called the Fisher-Pry ratio. Against time, the Fisher-Pry ratio plots as a straight line on a semilogarithmic graph, as shown in Figure 2.

Figure 2
Linearized Fisher-Pry Model



The right-hand scale on the graph shows the market penetration of the new technology. The semilogarithmic graph is commonly used when analyzing data because it is easier to visualize than an S-shaped curve. The S-shaped curve is more often used for the presentation of results because it is easier to explain and interpret.

Forecasting with Fisher-Pry

With the Fisher-Pry model, the future course of a partially-complete substitution can be forecast. Using linear or non-linear regression analysis, historical data can be used to obtain estimates for the parameters **a** and **b**. These estimates can then be entered into the Fisher-Pry equation to obtain projections for future years.

In some cases it is necessary to forecast the adoption of a new technology before it has begun to penetrate the market. Lacking historical data, forecasters can turn to analogies. For example, if similar historical substitutions occurred at substitution rates from 50% to 100%, one can posit that the new substitution may occur at the rate of about 75% (or 50%, to be conservative). Also, expert opinion and other forecasting techniques can be used to aid in estimating the appropriate rate.

Extensions of Fisher-Pry

In practice, not all technology substitutions exactly follow the Fisher-Pry model. For example, in some telecommunications substitutions, an early rapid rate of substitution has been observed to prevail up to the 10% level of substitution, followed thereafter by a somewhat slower rate. Beyond the 90% substitution point, the rate tends to increase again. Forecasts can be adjusted to account for this deviation by referring to historical substitutions as analogies.[3] In the case of multiple substitution, described below, and in other situations, such as capital constrained substitution, a more rigorous approach can be taken.

Multiple substitution occurs when the substitution of one technology for another is in progress and a third technology enters the market. For example, digital switching was introduced before analog electronic switches had completely replaced electromechanical switches so both analog and digital switches were substituting for electromechanical. Research over the past seven years has provided an improved understanding of multiple substitution, and practical techniques have been developed for dealing with it.[4]

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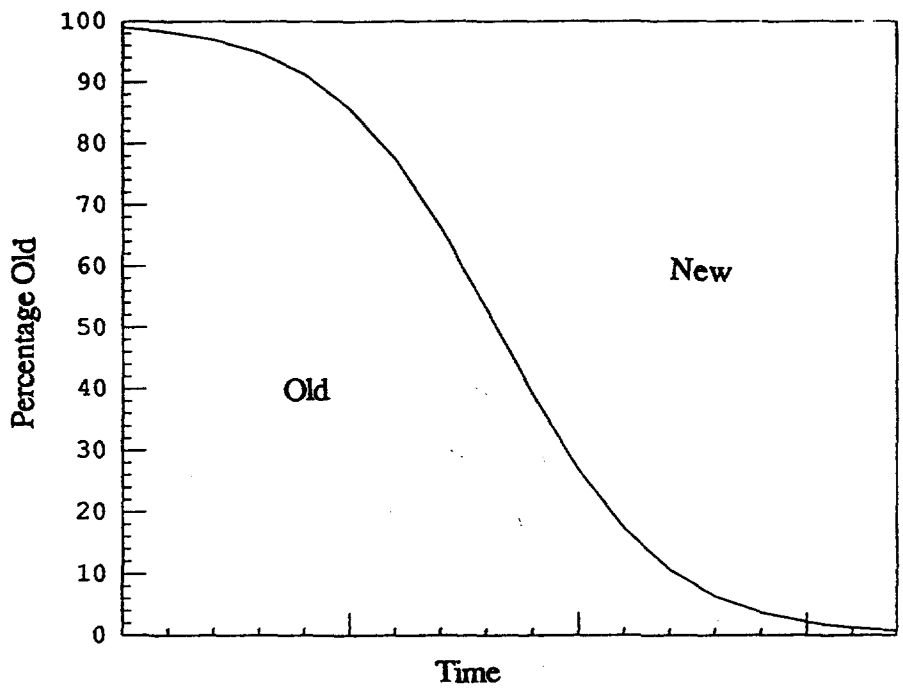
[3] For example, see Lenz and Vanston, *Comparisons.*

[4] See John W. Keith, "*Applications of the Fisher-Pry Model to Non-Homogeneous Technological Populations*," NYNEX Service Company, 1987, included as Appendix H. in L. K. Vanston and R. C. Lenz, *Technological Substitutions in Transmission Facilities for Local Telecommunications* (Austin, TX: Technology Futures, Inc., 1988). Also, see L. K. Vanston and R. C. Lenz, *Technological Substitution in Switching Equipment for Local Telecommunications* (Austin, TX: Technology Futures, Inc., 1988), pp. 11-16.

Projecting the Market Share of the Old Technology

The market remaining for the old technology is derived by simply subtracting from 100% the percentage of new technology determined by the Fisher-Pry model. This is the same as reversing the S-shaped curve as shown in Figure 3.

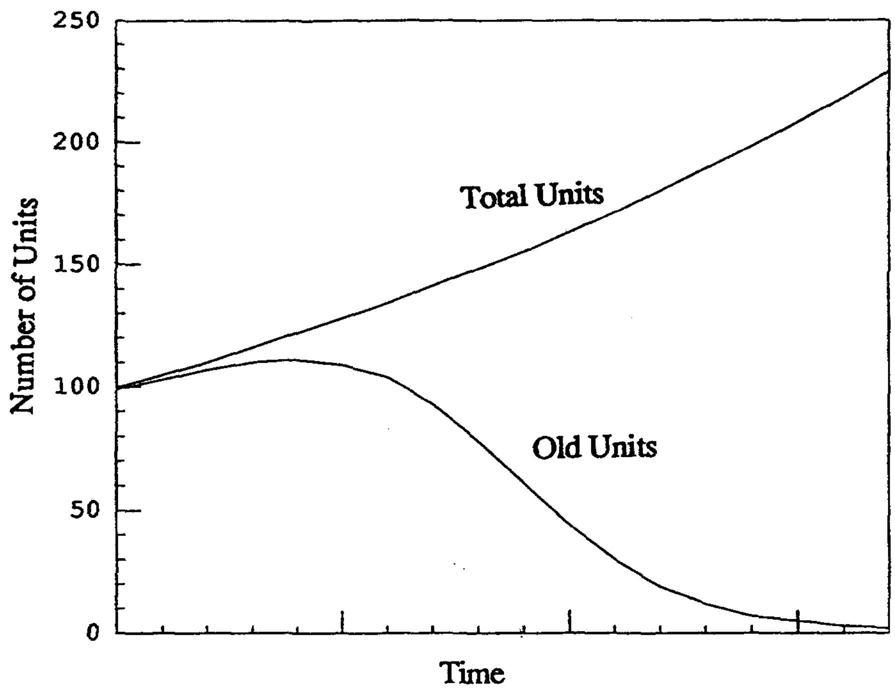
Figure 3
Market Share of the Old Technology



Projecting the Number of Units

The Fisher-Pry model predicts the *percentage* of new and old technology. To calculate the *number* of units of each, an independent forecast of the total market must be made. Multiplying the total by the percentages yields the number of units of the old and new technology. Figure 4 illustrates how growth (in this case, a 5% per year growth rate) affects the number of units of the old technology. Although the old technology is losing market share, it can continue to grow for several years after the introduction of the new technology. The faster the growth, relative to the substitution rate, the larger the effect.

Figure 4
Projecting the Number of Units



Relationship to Product Life Cycles

The product life cycle shows the units of a technology in service over time. Fisher-Pry can be used to forecast the product lifecycle on a percentage basis, which can then be used to state the forecast in terms of the number of units. Basically, when a technology is new, its S-shaped substitution curve forms the upside of the product life cycle. When a newer technology comes along, the reverse of its S-shaped substitution curve forms the down side of the product lifecycle for the earlier technology. This process is illustrated in Figure 5a. This simple explanation applies only when the substitutions do not